

Phase Space Acceptance of the NLC Positron Pre-Damping Ring

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Abstract

We review the results presented in the NLC ZDR leading to the design criteria of 0.09 m-rad horizontal and vertical transverse acceptance and 1.5% energy acceptance for the positron pre-damping ring. These criteria have been assumed for subsequent studies of the pre-damping ring to the present date. We propose that for the next stage of design work on the pre-damping ring, a relaxed acceptance of 0.045 m-rad horizontal and vertical transverse acceptance is assumed.

1. Transverse acceptance

The NLC main damping rings (MDRs) are currently being designed to accept a round beam with normalized emittance 150 mm-mrad, and produce a flat beam with normalized emittance 3.0 mm mrad (horizontal) by 0.03 mm mrad (vertical). The positron source is expected to produce a beam with emittance several orders of magnitude greater than that accepted by the MDRs, hence the need for a pre-damping ring. The transverse acceptance of a ring is determined by the physical and dynamic apertures, and the lattice functions through the ring; achieving a large acceptance presents technical challenges, and has cost implications. In the ZDR, a lower limit on the acceptance of the PPDR was imposed by the size of the beam produced by the positron source. In the next stage of design work, it may be desirable to reduce the acceptance criteria, in the assumption that the positron source can be improved to produce a smaller beam.

For a single particle, the unnormalized emittance is given in terms of the action:

$$\mathcal{E}_x = \frac{1}{2} (\gamma x^2 + 2\alpha x x' + \beta x'^2)$$

In a storage ring, this is $1/\pi$ times the area of the ellipse in phase space bounded by the particle on successive turns. For a gaussian beam, the rms emittance is given by:

$$\mathcal{E}_x = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2}$$

The beam coming from the positron source is not expected to be gaussian, and the distribution in the storage ring is not modified until the beam is damped close to equilibrium. For this reason, the ZDR gives the transverse acceptance in terms of an effective emittance, defined by the FWHM of the distribution¹:

$$\mathcal{E}_{eff} = 0.4 \text{ FWHM}$$

Assuming a flat distribution, we then find

$$\varepsilon_{\text{eff}} \approx 0.7 \varepsilon_{\text{edge}} \quad (1)$$

The 0.09 m-rad acceptance² for the ZDR pre-damping ring design, refers to the normalized edge emittance of the injected beam³. We note that it is assumed that even with this large acceptance, 20% of the delivered charge is lost at injection into the pre-damping ring⁴. Also, the pre-damping ring is designed to operate with a maximum bunch charge 20% greater than that required at the IP.

The actual normalized edge emittance of the injected beam in the ZDR is⁵ 0.06 m-rad. This is determined by the acceptance of the positron capture system, up to the entrance of the L-band 2 GeV booster linac⁶. The positron output from the target was calculated for the ZDR using the EGS program, and the phase-space distribution at the end of the capture linac was then found by ray-tracing⁷. Using (1), the value of 0.06 m-rad for the injected normalized edge emittance is consistent with Emma's assumption of 0.042 m-rad for the injected normalized rms emittance⁸, and the value of 0.04 m-rad quoted by Sheppard et al⁹.

Injection mismatches and other effects¹⁰ (which may not be well understood) can increase the effective emittance by 50%; hence the acceptance value of 0.09 m-rad for the normalized edge acceptance. The specification for the injection errors is based on the assumption that the amplitude of the transverse beam "jitter" is equal to the beam size¹¹.

Studies of the pre-damping ring for the ZDR showed a dynamic aperture¹² significantly in excess of 0.09 m-rad, even in the presence of field and alignment errors, and a momentum aperture of 2%.

2. Longitudinal Acceptance

At the end of the positron capture linac (250 MeV), the energy spread is $\pm 6\%$; this reduces to $\pm 1.8\%$ at the end of the booster linac¹³. An RF acceptance of $\pm 1.8\%$ would require an RF voltage in excess of 3.5 MV in the pre-damping ring. In the ZDR design, therefore, an energy compressor was included between the end of the L-band booster linac and the PPDR injector¹⁴. The energy compressor reduces the energy spread to $\pm 1\%$, and also reduces the jitter to¹⁵ $\pm 0.2\%$ rms. The RF voltage of the PPDR was then chosen to be 2.0 MV, which gives a bucket height of¹⁶ $\pm 1.5\%$. Another effect of the energy compressor system is that the bunch length, σ_z , is increased from¹⁷ 3.7 mm to 6.97 mm (note that the distribution in longitudinal phase space is highly non-gaussian). A recent design for the pre-damping ring⁸ gives an extracted energy spread, σ_δ , of 0.089% and an extracted bunch length, σ_z , of 7.53 mm.

3. Proposed Acceptance Values

The required acceptance values for the pre-damping ring most directly affect the designs of the magnets in the lattice, since these must have a sufficiently large bore to allow the passage of particles with betatron amplitudes and/or momentum deviations up to the acceptance values. In a recent design⁸, the quadrupoles and sextupoles in the arcs have a pole-tip radius of 50 mm, with a maximum field of 0.81 T. Reducing the acceptance will

allow a reduction in the pole-tip radius and a corresponding increase in field gradient, and will significantly ease the design work, giving a greater scope for effective solutions.

We therefore propose the values shown in Table 1 for the transverse and longitudinal acceptance of the positron pre-damping ring, for the next phase of design work.

Table 1

Proposed acceptance values for next phase of pre-damping ring design work.

Assumed injected transverse edge emittance (horizontal and vertical)	$\gamma\epsilon_{edge}$	0.03 m-rad
Assumed injected transverse jitter (horizontal and vertical)	$\Delta\gamma J$	0.015 m-rad
Transverse acceptance (normalized edge emittance)		0.045 m-rad
Assumed injected energy spread	$\sigma_{\Delta E/E}$	1%
Assumed injected energy jitter	$\Delta E/E$	0.2%
Energy acceptance		1.5%
Assumed injected bunch length	σ_z	6.97 mm

References

- ¹ *Zeroth-Order Design Report for the Next Linear Collider (ZDR)*, 1996, page 125.
- ² *Recent Developments in the Design of the NLC Positron Source*, T. Kotseroglou et al, Proceedings PAC 1999.
- ³ ZDR, pages 123-124.
- ⁴ ZDR, page 120.
- ⁵ ZDR, page 123.
- ⁶ ZDR, pages 98-99.
- ⁷ ZDR, pages 90-91.
- ⁸ *Preliminary e^+ Pre-Damping Ring Design for the NLC*, P.Emma, SLAC Memorandum, March 24, 1999.
- ⁹ *The NLC Injector System*, J.C.Sheppard et al, Proceedings, PAC 1999.
- ¹⁰ ZDR, page 124.
- ¹¹ ZDR, pages 122-123.
- ¹² ZDR, page 164.
- ¹³ ZDR, pages 98,100.
- ¹⁴ ZDR, pages 132, 150-151.
- ¹⁵ ZDR, page 123, Table 4-4.
- ¹⁶ ZDR, page 132.
- ¹⁷ ZDR, page 151, Table 4-9.